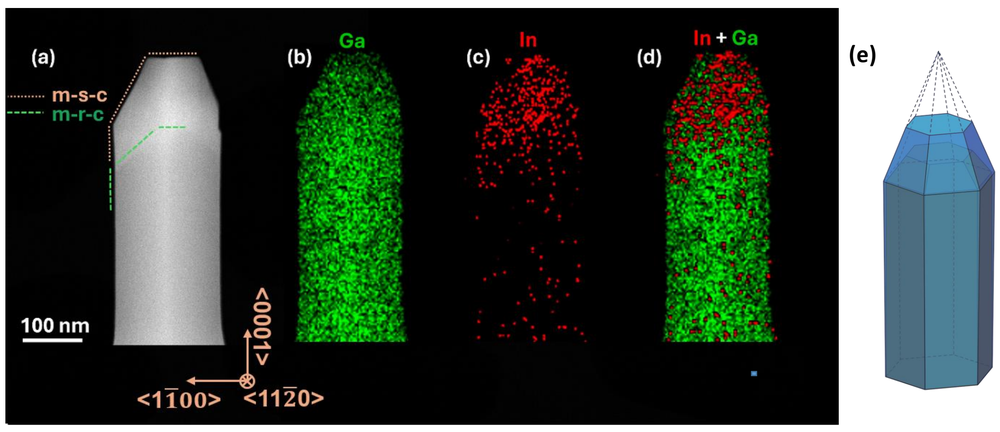
# Morphological transformation of (In,Ga)N nanoshells grown around pencil-like GaN nanowires

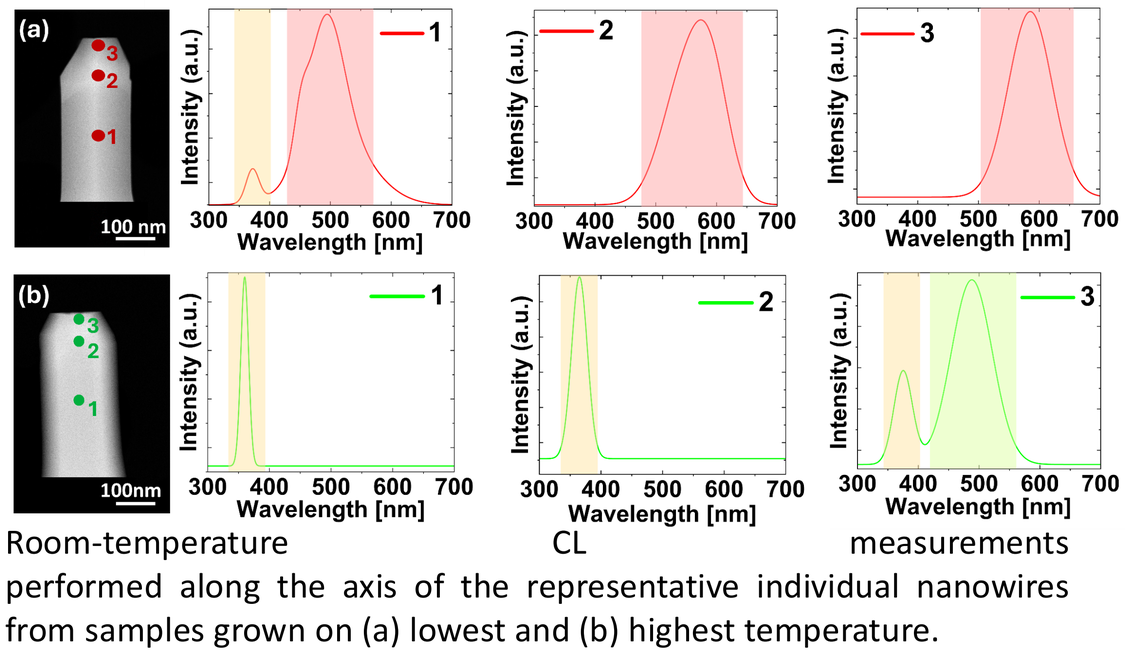
**Abstract:** Although GaN/(In,Ga)N/GaN nanowires have previously been demonstrated as hosts for single-photon emission centers, the random spatial distribution of these centers within the nanowire remains an open challenge for the scientific community. To address this issue, we have grown a simpler structure and analyzed the transition from m-r-c crystal planes in the GaN core to m-s-c crystal planes in the (In,Ga)N nanoshell. Moreover, by preparing a series of samples in which only one growth parameter (either the initial In impinging flux or the temperature) was varied, we investigated In incorporation across different regions of the nanowire. Low-temperature µPL measurements revealed sub-meV FWHM emission peaks, suggesting that these simpler structures may indeed host single-photon emission centers.

## Nanowire structure

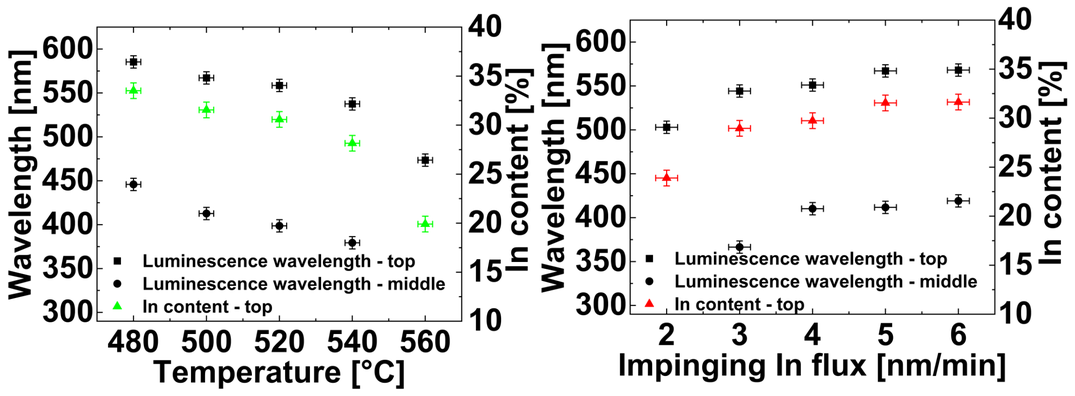



(a) HAADF-STEM image of a single nanowire. (b) X-EDS Ga distribution map (using Ga-Lα signal). (c) X-EDS In distribution map (using In-Lα signal). (d) The superposition of both X-EDS Ga and In distribution maps (Ga-Lα + In Lα signals) is also shown clarity. (e) 3D model of a final form of the nanowire.

## In incorporation – CL measurements

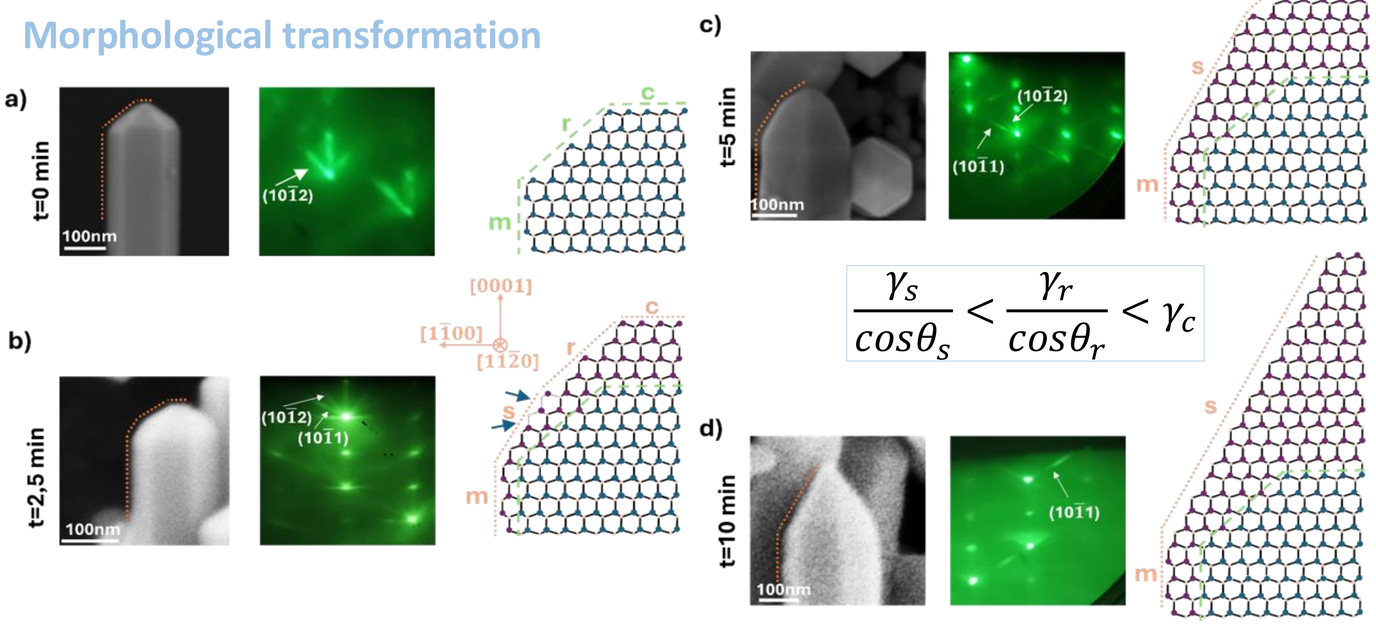



Room-temperature CL measurements performed along the axis of the representative individual nanowires from samples grown on (a) lowest and (b) highest temperature.




$$E_g(x) = xE_g(InN) + (1-x)E_g(GaN) - bx(1-x),$$
$$E_g(InN) = 0{,}65eV,\ E_g(GaN) = 3{,}44eV,\ b = 2{,}1 \pm 0{,}3eV$$

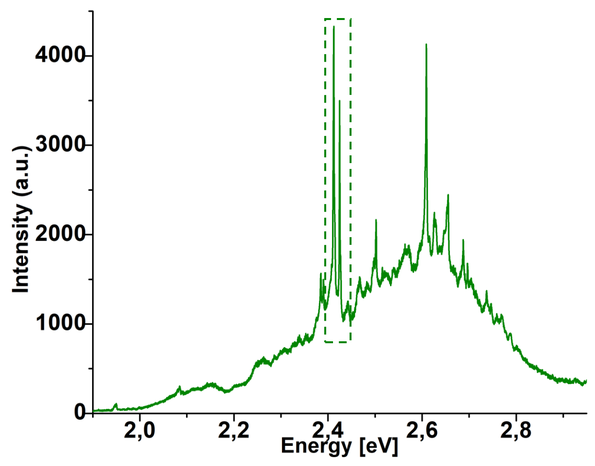
## Morphological transformation




$$\frac{\gamma_s}{cos\theta_s} < \frac{\gamma_r}{cos\theta_r} < \gamma_c$$

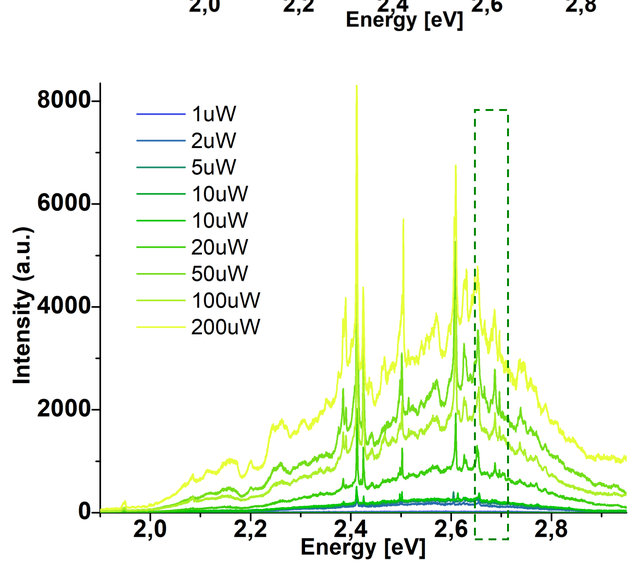
Stages of the (In,Ga)N nanoshell growth, with a cross-view SEM image of a single representative NW, RHEED diffraction pattern obtained along [11-20] azimuth and an atomic sketch of the NW tip. (a) initial GaN NW, (b) truncated "quasi-pyramid" shape, (c) "quasi-pyramid" shape and (d) pyramid shape

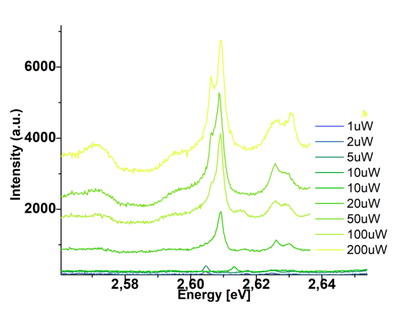
## Potential single photon emission centers – µPL measurements




| | VALUE | ERROR |
|---|---|---|
| FWHM1 | 5,59644e-4 | 4,59965e-5 |
| FWHM2 | 8,69435e-4 | 1,738737e-4 |

Low temperature µPL measurement, with feated two emission peaks, showing narrow emission lines with FWHM below 1meV.



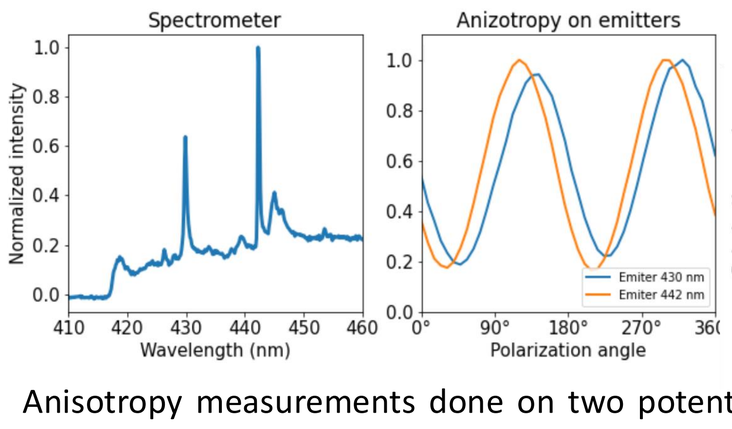




Low temperature power-resolved µPL measurement, noted appearance of biexcitons for higher entrance power in some of the emission lines.

## Conclusion

- We have developed a detailed model describing the morphological evolution of the nanoshell tip during epitacial growth, witch, under already mentioned theoretical assumptions, aligns well with the theoretical trend for GaN formation.
- We gave an insight into indium incorporation within the (In,Ga)N nanoshell, highlighting the changes in incorporated quantity based on different growth parameters (indium flux and temperature) as well as crystal plane. Important takeaway is that, considering the abovementioned geometrical transformation, indium incorporation cannot always be clearly linked to a specific crystal plane.
- We have shown with low-temperature µPL measurements that these samples have strong linearly polarized narrow emission lines. With a final confirmation by the use of $g^{(2)}(0)$ correlation function that these are indeed emission lines coming from single photon sources, we would open the doors to cheaper and faster production of single photon emission centers.

## Polarization of emission lines




Anisotropy measurements done on two potential single photon emitters, both on the spectra and on the map, showing strong linear polarization of both emitters.

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*Proyecto MADQuantum-CM, financiado por la Comunidad de Madrid y por el Plan de Recuperación Transformación y Resiliencia, financiado por la Unión Europea – NextGenerationEU*

*We acknowledge the financial support provided by the European COST Action OPERA (CA-20116) through the short-term scientific missions program*